A Simple Quirk Hunt Using HSCP Tools

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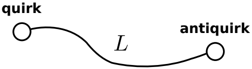
What are quirks?

- A new $SU(N)'$ gauge group added to the Standard Model with:
  - new fermons Q with $100 \lesssim m_Q \lesssim 1000\ \mathrm{GeV}/c^2$: "quirks"
  - strong interactions *below* the TeV scale, $\Lambda \ll m_Q$: "infracolor"
- Weird phenomenology: macro or mesoscopic strings (flux tubes)



$$L \sim \frac{m_Q}{\Lambda^2} \sim 10\ \mathrm{m} \left(\frac{m_Q}{\mathrm{TeV}}\right) \left(\frac{\Lambda}{100\ \mathrm{eV}}\right)^{-2}$$

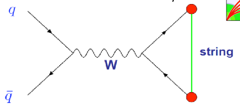
- Kang & Luty, *Macroscopic Strings and "Quirks" at Colliders* (2009) `http://iopscience.iop.org/1126-6708/2009/11/065/` (arXiv:0805.4642), see also cited-by: Quirky Dark Matter, SUSY quirks, and the *Wjj* excess

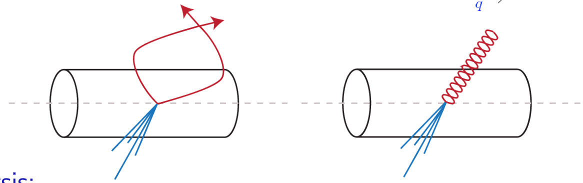
Is this motivated by electroweak symmetry breaking/ the hierarchy problem/other theoretical problem?

- No: it is a possibility that is consistent with known data, and might be missed without a deliberate search
- Comparable to Z', which is an extra $U(1)'$ that may or may not come from the breaking of a larger GUT group

Signatures

Infracolor string connecting quirks does not break, so quirks orbit each other through the detector





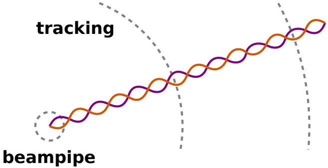
This analysis:

- Straight track from mesoscopic quirk string: 10 keV $\lesssim \Lambda \lesssim$ 1 MeV, quirks with electric charge but no QCD color

Other quirk signatures, not pursued here:

- Tracks curving in r-z plane: $\Lambda \ll$ 10 keV
- Free end of a string orbiting a stopped quirk (spiral track)
- Hadronic fireball (many soft hadrons): quirks with QCD color
- same with a displaced vertex: $c\tau \sim \frac{m_Q}{\Lambda_{\mathrm{QCD}}} \frac{m_Q}{\Lambda^2} \sim 100\ \mu\mathrm{m} \left(\frac{\Lambda}{\mathrm{MeV}}\right)^{-2} \left(\frac{m_Q}{\mathrm{TeV}}\right)^2$
- Prompt annihilation or decay to infracolor glueballs: $\Lambda \gg$ MeV

Focus on the simplest signature

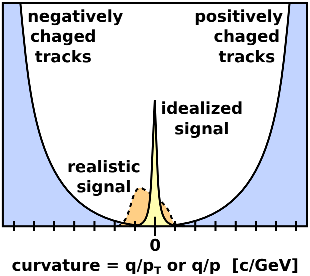


electrically charged quirks, far enough apart to ionize atoms and make a track

close enough to not be resolved as two tracks or confuse the track-fitter

therefore, we observe one zero-curvature track

- Unlike *all* backgrounds, the signal peaks at curvature = 0
- If realistic distortions to curvature distribution can be quantified as nuisance parameters, search/limits can be performed with a fit (bump-hunt)



Since this object also has mass $\geq 2m_Q$, it will be slow ($\beta \ll 1$)

- Tracker dE/dx and muon time-of-flight will be useful cuts
- Mass varies event-by-event; it would not peak in HSCP mass plot

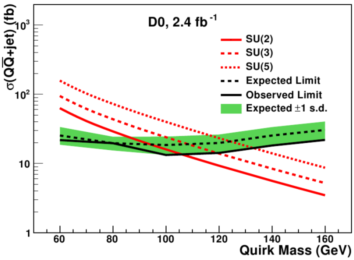
Previous searches

This technique was used by DØ (2.4 fb^{-1}, fall 2010)

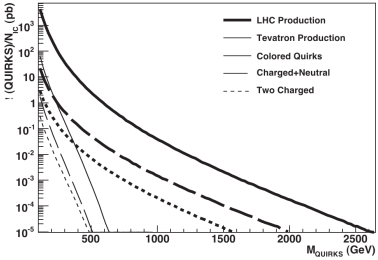
- as a counting experiment, not bump-hunt
- not triggered in muon system: associated with jet and $\not\!\!E_T$

http://prl.aps.org/abstract/PRL/v105/i21/e211803 (arXiv:1008.3547)

DØ limits



Tevatron and LHC cross-sections



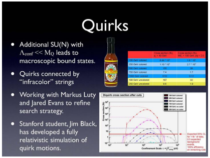
- 95% C.L. limits on quirk mass: 107, 119, 133 GeV$/c^2$ for $SU(2)'$, $SU(3)'$, $SU(5)'$, respectively (10 keV $< \Lambda <$ 1 MeV)
- LHC ($E_{\mathrm{CM}} =$ 10 TeV? 7 TeV?) can reach much higher in quirk mass

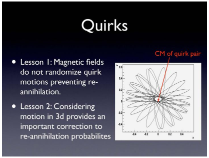
Triggering

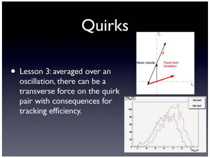
- For $\beta > X$, quirk pair reaches the muon system within timing window: use highest-p_T unprescaled single-muon trigger available
  - 1.5 bunch timing windows $=$ 40 ns, muon system is 15 ns away from the beamspot, so $X = 0.4$?
  - I do not yet know the β distribution for this model at the LHC
  - At the Tevatron, β distribution is "very wide and peaks at $\beta \sim$ 0.8 (0.2) for $m_Q = 60$ (160) GeV/c^2" (DØ paper)
- For $\beta < X$, must trigger on the jet or photon that is produced with the quirk pair
  - I don't know jet/photon distributions for the LHC yet, either
  - DØ analysis required exactly one $p_T > 75$ GeV/c jet in $|\eta| < 1.6$ and $\not{E}_T > 50$ GeV

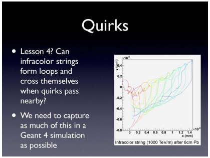
The single-muon trigger case is a subset of HSCP data, but the "jet or photon" is not (unless our calculation of $\not{E}_T$ excludes the HSCP track and we can expect large $\not{E}_T$)

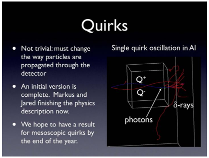
- I'm writing to Markus Luty about using the same simulation as DØ
  - β distribution and associated jet or photon for trigger
  - classical trajectory and Bethe-Bloch dE/dx for ionization
- However, Tim Nelson and Jim Black (SLAC/ATLAS) are developing a much more realistic simulation of quirk propagation through matter: `http://online.kitp.ucsb.edu/online/lhc11/nelson/`











- We should use this MC when it becomes available

Future extensions

- Straight-track propagation is a special case in three important ways:
  - infracolor string is required to be short compared to track hits
  - infracolor string is required to be long compared to atoms
  - quirks assumed to have zero QCD color
- Three ways to generalize this analysis:
  - expand track reconstruction to allow for curvature in the r-z plane: this would allow for longer infracolor strings ($\Lambda < 10$ keV) and may double as a monopole search
  - search for hadronic fireballs and displaced fireballs: this would allow for quirks with QCD color (outside of HSCP group)
  - displaced dileptons and diphotons would capture the microscopic string case (partly covered elsewhere)
- I only have resources to do the simple straight-track search
- There are many more opportunities for people looking for a project

Steps in the straight-track analysis

1. Walk through Hscp2011Analysis twiki (done)
2. Obtain a quirk MC and integrate it into CMS (follow HSCP stau/stop/gluino examples to see how to add slow particles with large dE/dx? does Geant do this for us?)
3. Produce the analysis plot (curvature histogram, where signal peaks at zero) and *roughly* optimize cuts with MC
4. If a lot of the signal is out-of-time with the muon trigger, identify a good jet or photon trigger and produce a second sample
5. Use previously-studied trigger efficiency results (muon trigger as a function of β and other triggers generically)
6. Calculate track-reconstruction efficiency as a function of infracolor string length (using Nelson and Black's realistic MC)
7. Study resolution of curvature $= 0$ peak from alignment and $Z \to \mu\mu$
8. Finalize cuts, fitting procedure, and limit/discovery procedure with MC and blinded data (blind in curvature and/or dE/dx)
9. Unblind and fit; write results as an independent Analysis Note and as a part of an upcoming HSCP paper

Conclusions

- Quirks are a possible extension of the Standard Model with bizarre (fun) phenomenology
- As far as I'm aware, there are no quirk analyses in CMS
  - searching for "quirks" in HyperNews and Indico only result in messages about computer problems
  - in several old talks, Albert de Roeck tried to raise interest
- The straight-track signature is *almost* a special case of the HSCP analysis; I think it should be presented as such
- There are many other quirky signatures to look for